Impact of Value of Time (VOT) on toll roads

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Abstract

This paper provides a brief overview of the concept of value of time (VOT), in the context of toll road schemes. VOT analysis determines the tradeoffs travelers make between time and tolls. The analysis is very important when considering the choice between tolled and un-tolled alternatives. Using travel demand model of Fresno, CA, I provide a sensitivity analysis showing how the outcomes of tolling schemes can change with varying VOT levels.

Keyword- Value of time, Road pricing, Congestion pricing, Optimal toll, Profits, System-wide costs.

Introduction and Summary

Value of time (VOT) is a measure that transportation practitioners employ in order to estimate how users of toll roads (or other facilities) make choices between a cost component and a time component of each trip (Rouhani and Niemeier, 2014a,b; Rouhani et al., 2014b; Rouhani et al., 2015a,b). In fact, VOT explains the tradeoff between time and money (Brownstone and Small, 2005; Small, 2012).

We can explain the application of VOT concept using a simple example. Assume that a user have to options to reach its destination:

- Path 1: time: 0.5 hour, no tolls
- Path 2: time: 0.3 hour, $4 of tolls

The question is which path would be the choice of the user? Without any toll, all users would generally choose Path 2 since it is faster (lower travel time). However, with a toll on Path 2, some users might want to avoid Path 2 now since they have to pay money out of their pocket. Rich users or those ones that have urgent needs may want to pay more to save time. In other words, users should determine how they perceive these cost components relative to each other. Assuming a value of time measure, user can calculate a general costs instead of time cost only when roads are priced. For example, with a value of time of $10/hour, Path 1 has a general cost of \$5 (0.5*10) and Path 2 has a general cost of \$7 (0.3*10+4). With such calculation, users can choose their paths.

VOT determines how users value time spent driving (travelling) and how they calculate a more general cost of travel (Rouhani and Niemeier, 2011; Rouhani, 2012; Rouhani et al., 2014a). For user *i* and each alternative mode *j*, GC_i is the general cost of travel and can be calculated as follows:

$$GC_i = VOT_i . t_j (v_j) + C_j \quad (1)$$

where t_j is the travel time spent and C_j is the price or the toll paid by each user. Travel time is a function of traffic volume (v_j) or congestion level. VOT_i is the value of time (\$/hour) which transforms time (in hours) into a monetary measure (\$). Note that a more general cost could include fuel costs (Rouhani and Zarei, 2014; Rouhani and Gao, 2014), especially considering huge environmental and energy footprints of the fossil fuel burning from transportation (McCubbin and Delucchi, 1999; Lin et al., 2009; Rouhani et al., 2010; Madani et al., 2011; Mirchi et al, 2012; Rouhani, 2013).

Using different VOTs, a specific time cost of tolling ($VOT_i . t_j (v_j)$ in Equation 1) will be translated in different monetary costs of tolls, i.e., a 10 minute–equivalent toll equals to \$5 using a \$30/hour VOT and equals to \$10 using a \$60/hour[1]. Under the same flow pattern, a higher average VOT will result in a higher toll rate (monetary) and consequently a higher revenue by a constant ratio. Note that to do a thorough analysis, we need to use the Multi-user concept since users have perception about their VOT's. Users are different in the way they incur tolls. When evaluating tolling schemes, a multi-user feature (Yang and Huang, 2004; Chen and Bernstein, 2004; Rouhani and Niemeier, 2011) is necessary for any equity analysis (Levinson, 2010).

VOT depend on so many factors such as income, type of trip, the quality of alternative paths/modes, etc (Hess et al., 2005). To estimate VOT, consider that traveler *i* chooses to maximize a random utility function (Lam and Small, 2011):

$$U_{itj} \equiv \theta_{ij} + \beta_i X_{itj} + \varepsilon_{itj} \quad (2)$$

where X_{itj} is the vector of variables affecting utility gained the time *t* of the choice. The vector include the toll C_{itj}, travel-time T_{itj}, and (un)reliability R_{itj}, etc. Therefore, the value of travel time is defined as:

$$VOT_i = \frac{\partial U_{itj} / \partial T_{itj}}{\partial U_{itj} / \partial C_{itj}} \quad (3)$$

[1] The time cost of tolls is the main driver of the difference in users' travel behavior.

The derivatives in the above equation allow VOT to depend not only on the individual traveler *i* but also on the alternative *j* or choice of time *t*. VOT is a very important measure in evaluating road pricing (Rouhani, 2009; Rouhani, 2014), congestion pricing (Prud'homme and Bocarejo, 2005; de Palma and Lindsey, 2011; Rouhani et al., 2014b), and public-private partnership tolling schemes (de Bettignies and Ross, 2004; Boardman and Vining, 2012; Rouhani et al., 2015a), and in calculating social and private costs of driving (Rouhani et al., 2013b).

In this paper, I analyze the impact of VOT on several measures related to toll collection revenues and costs and their associated system-wide travel costs (system performance). The analysis is conducted using the travel demand model of the City of Fresno, California. The assumptions made for the calculation is available from Rouhani et al. (2013a), Rouhani and Gao (2014), and Rouhani and Gao (2015b).

Results

It is essential to run a sensitivity analysis on several key parameters of any model (Rouhani et al., 2013b; Rouhani et al., 2014b) that impact outcomes of a tolling scheme. One of the most important variables is VOT. As we discussed, Value of time (VOT) is one of the major elements in analyzing P3 projects (Rouhani et al., 2015a). Considering several base parameters, we can calculate the effects of various VOT rates on the tolling schemes' outcomes. Note that my analysis takes into account the effects on the whole network of a metropolitan area, not only the effects on the facility of concern (Safirvoa et al., 2007). Figure 1 shows the changes in optimal profit, optimal revenue, and profit-optimal toll rate as VOT level increases. The optimal toll and profit are shown for one typical highway (Figures 1–a) and one typical arterial (Figures 1–b) and for peak (Figures 1–1) and off-peak (Figures 1–2) periods. The method used to for calculating revenues, profits, and optimal tolls can be found in Rouhani et al. (2015a).

Although highly effective on the results, an average VOT (not a detailed classified VOT study) only affects the tradeoffs between money (tolls) and time. Figure 1 displays that optimal revenue is linearly related to VOT (constant ratio). However, the effects of VOT on the optimal-profit toll and optimal profit are not as simple. Even optimal toll may decrease with VOT (Figure 1–a–2) since private owners might find it more profitable to decrease tolls and attract more demand even with higher tolls. We find that this counterintuitive result has higher chances of occurrence in off-peak hours, due to a more elastic demand. However, the addition of heterogeneous users in terms of VOT could drastically impact the results. Finally, VOT sensitivity analysis should be combined with the analysis on demand risk (Chen and Subprasom, 2007), other risks associated with tolling (Jin and Zhang, 2011), operating costs (Rouhani et al., 2014c), etc.

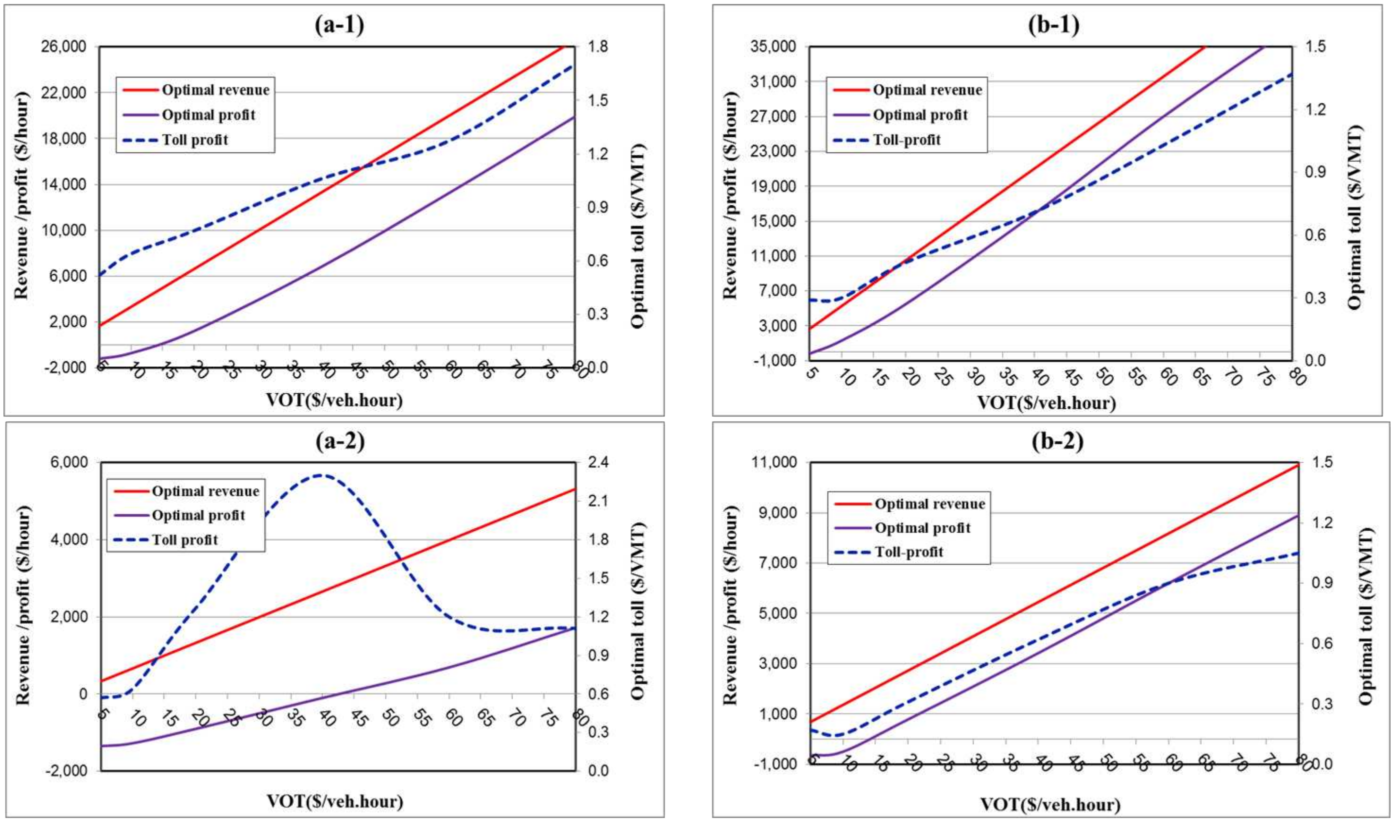

Figure 1. Sensitivity of the revenue, profit, toll with respect to average VOT for (a) a typical Highway and (b) a typical Arterial No.1 and for (1) peak vs. (2) off-peak.

For Highway and in peak periods, the sensitivity of system-optimal toll rates to changes in average VOT and fuel prices is shown in Figure 2. System-optimal rates are found using a very complex optimization problem (Poorzahedy and Rouhani, 2007; Madani et al., 2014) Although system-optimal rates minimize the total system travel costs including time, fuel, and emissions costs in monetary terms (Rouhani et al., 2015a), the dominance of travel time cost relative to other travel cost components (Rouhani et al., 2013c) leads to a rate that minimizes total travel time only (Yang, 1999). Unless the VOT is very low or the fuel prices are very high, the system–optimal rate remains the same. Even when the rate changes, the change is very small ($0.25 to $0.26/mi). This result holds true for almost all other tolling systems (on all other roads). Although taking the fuel consumption and emissions costs into account have negligible effects in determining system-optimal rates, the magnitude of travel costs and the related system-wide benefits or costs could be greatly affected by taking them into account.

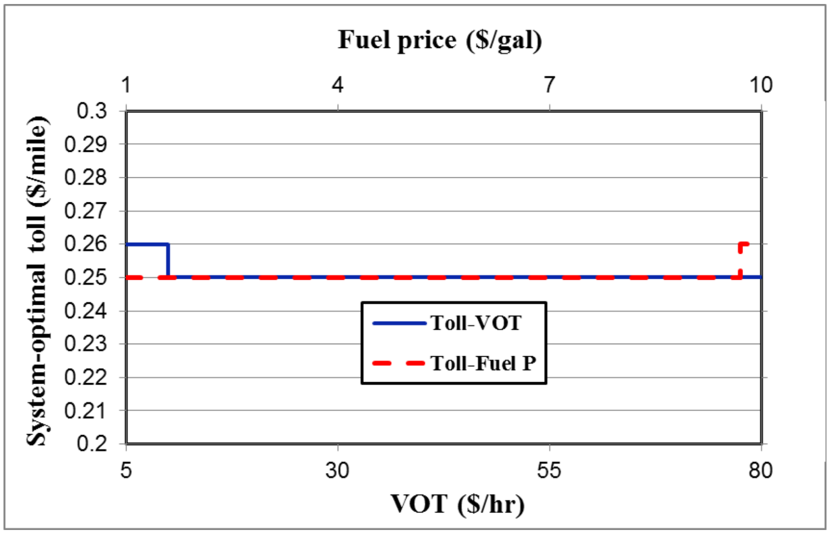

Figure 2. Sensitivity of the system-optimal tolls to average VOT and fuel price for a typical highway in peak hours.

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